APPENDIX A
DERIVATION OF MERCURY-SPECIFIC ALGORITHMS AND INPUT PARAMETERS

This appendix contains derivations of chemical-specific algorithms, parameters, and information used to derive those parameters. The majority of the appendix focuses on chemical transformations, but information on uptake and distribution of chemicals is also included.

A.1 MERCURY-SPECIFIC ALGORITHMS

A.1.1 PLANT MESOPHYLL RESISTANCE

A general plant algorithm for mesophyll resistance was added to TRIM.FaTE because of the properties of mercury. For most organic chemical species and most plant species, the stomatal or cuticular conductance is the rate-limiting pathway (Riederer 1995). Therefore, for many chemicals, there is no need to consider mesophyll (inner tissue) conductance. However, some work with mercury cited in Lindberg et al. (1992) suggests that "resistance on or within mesophyll surfaces dominates the atmosphere-leaf diffusive path of Hg(0)."

In herbaceous species, it may be assumed that this mesophyll resistance is a factor of 2.5 x stomatal resistance (Lindberg et al. 1992) and that mesophyll conductance is a factor of 1/2.5 or 0.4 x stomatal conductance. It is suggested that the following equation be used for elemental mercury only:

$$g_m = g_{Stomata} \times 0.4$$

where:

g_m = conductance of chemical through mesophyll (m/d)

It should be noted that the high mesophyll resistance of elemental Hg may be due to its assimilation in mesophyll tissue (Lindberg et al. 1992). It has previously been assumed that the mesophyll resistance for divalent mercury is 0 (U.S. EPA 1997a); *i.e.*, that g_m is infinite. It is assumed that mesophyll resistance for methylmercury is also 0, based on a lack of information.

A.1.2 ALGAE

The uptake of pollutants by algae is generally assumed to occur by passive diffusion. The algorithm for chemical uptake by algae in TRIM.FaTE has only been derived for mercury at this time.

Passive uptake of uncharged, lipophilic chloride complexes is the principal accumulation route of both methylmercury and inorganic mercury in phytoplankton and is determined by water chemistry, primarily pH and chloride concentration (Mason et al. 1996). Mason and others

(Mason et al. 1995, Mason et al. 1996) developed an accumulation model for the marine diatom (*Thalassiosira weissflogii*) and modified it for use with "typical" freshwater algae for the purposes of predicting mercury accumulations in fish. It assumes that uptake via passive diffusion is determined by the overall K_{ow} (*i.e.*, the D_{ow}) for the neutral mercury complexes present in solution. The D_{ow} is given as the sum of the individual K_{ow}s for each mercury species by the following equation (Mason et al. 1996):

$$D_{ow} = \sum f_i \left(K_{ow}\right)_i$$

Where f_i = mole fraction of total mercury present as species *i*. The fractional amount of total mercury present as each neutral mercury species was estimated as a function of pH and chloride concentration. The predicted inorganic mercury (divalent) and methylmercury D_{ow} for each of five pH levels (pH 4, pH 5, pH 6, pH 7, and pH 8) and for chloride concentrations ranging approximately from 0.01 mg/l to 10,000 mg/l was presented graphically in (Mason et al. 1996). These D_{ow}s in TRIM.FaTE were estimated based on those curves.

Uptake of inorganic mercury (divalent) and methylmercury by algae is given by the following equation (Mason et al. 1996)

$$Hg_{algae} = \frac{D_{OW} \times U \times 4\pi R^2}{\left(4/3\right)\pi R^3 \times \rho \times \mu} \times Hg_{water}$$

where:

Hg_{algae}	=	concentration in algae (nmol g^{-1})
Hg_{water}	=	concentration in water (nM)
D_{OW}	=	overall K_{OW} for neutral mercury complexes at specified pH and chloride concentrations (unitless)
U	=	algal surface area-specific uptake rate constant (nmol μm^{-2} d^{-1} nM^{-1})
R	=	average radius of algae (μm)
ρ	=	average cell density (g μm^{-3})
μ	=	growth rate constant (d^{-1})

Note that this equation uses moles. Gram weights are derived by multiplying the moles per gram or liter by the chemical-specific molecular weight. Table 7-1 shows the molecular weights of mercury and methylmercury in the units appropriate for converting the above algae (nmol g^{-1}) and water (nM) concentrations.

Table 7-1
Molecular Weights of Mercury and Methylmercury.

Chemical	Molecular Weight		
	g mol^{-1}	µg $nmol^{-1}$	mg $nmol^{-1}$
Hg	200.59	2.0059×10^{-1}	2.0059×10^{-4}
CH_3Hg	215.62	2.1562×10^{-1}	2.1562×10^{-4}

Uptake is assumed to be instantaneous relative to the time steps used in TRIM.FaTE, given that the process occurs in hours rather than days (Mason et al. 1996). Also, uptake of elemental mercury is assumed to be insignificant in TRIM.FaTE, based on the findings of (Mason et al. 1996) that the accumulation rates were less than 1 amol $cell^{-1}$ h^{-1} nM^{-1}, where amol equals 1×10^{-18} moles.

A.1.3 ACCUMULATION OF MERCURY BY FISH

Mercury concentrations in fish are ultimately determined by methylmercury accumulation at the base of the food chain (Mason et al. 1995, Mason et al. 1996). Therefore, one alternative algorithm for the uptake of mercury in fish based on the general equation for the time-to-steady-state food chain model is presented in Section 7.3.3. Intertrophic level concentration ratios ($K_{receptor\text{-}diet}$) were obtained from studies of natural populations of fish, zooplankton, and phytoplankton. Based on studies using MHg/N ratios in whole fish ,the concentration ratio between two trophic levels was found to generally be around 3 to 4 (studies cited in Lindqvist et al. (1991). As noted in Section 7.3.3, mercury transfers from algae to water column herbivores includes the intermediate transfer from algae to zooplankton. Concentration ratios between planktivorous fish and phytoplankton were between 9 and 16 (Lindqvist et al. 1991, Watras and Bloom 1992). That is, zooplankton were an intermediate trophic level and the transfers between each trophic level were approximately equal. Taking the geometric mean results in approximate concentration ratios for methylmercury of 3.5 for one trophic level transfer and 12 for two trophic level transfers (Mason et al. 1996).

Inorganic mercury (divalent) transfer factors between phytoplankton and zooplankton and between zooplankton and planktivorous fish are given by Watras and Bloom (1992). In the absence of similar factors for fish to fish transfers of inorganic mercury, the zooplankton to planktivorous fish transfer factor was used to estimate the concentrations in the water column omnivore, water column carnivore, benthic omnivore, and benthic carnivore compartment types.

A.2 INPUT PARAMETERS SPECIFIC TO MERCURY TRANSFORMATION

Since there are three species of mercury, there are six possible transformation routes from one species to another. All but one of these routes will be considered:

- Reduction $Hg(2) \rightarrow Hg(0)$
- Oxidation $Hg(0) \rightarrow Hg(2)$
- Methylation $Hg(2) \rightarrow CH_3Hg$
- Demethylation $CH_3Hg \rightarrow Hg(2)$
- Mer cleavage demethylation $CH_3Hg \rightarrow Hg(0)$

The route not considered is methylation of Hg(0), for which little information has been reported.

In the case of mercury, the transformation from one chemical species to another is modeled using a first-order rate constant. In particular, the following general equations are used to model transformation.

$$\textit{Reduction}, Hg^{2+} \rightarrow Hg^{0}: \quad \frac{dM_1}{dt} = k_r M_2(t)$$

$$\textit{Oxidation}, Hg^{0} \rightarrow Hg^{2+}: \quad \frac{dM_2}{dt} = k_o M_1(t)$$

$$\textit{Methylation}, Hg^{2+} \rightarrow CH_3Hg: \quad \frac{dM_3}{dt} = k_m M_2(t)$$

$$\textit{Demethylation}, CH_3Hg \rightarrow Hg^{2+}: \quad \frac{dM_2}{dt} = k_{dm} M_3(t)$$

$$\textit{Mer cleavage demethylation}, CH_3Hg \rightarrow Hg^{0}: \quad \frac{dM_1}{dt} = k_{mc} M_3(t)$$

where:

M_1	=	mass of elemental mercury [Hg(0)] in a compartment type
M_2	=	mass of divalent mercury [Hg(2)] in a compartment type
M_3	=	mass of methylmercury (CH_3Hg) in a compartment type
k_r	=	reduction rate in compartment type, 1/day
k_o	=	oxidation rate in compartment type, 1/day
k_m	=	methylation rate in compartment type, 1/day
k_{dm}	=	demethylation rate in compartment type, 1/day
k_{mc}	=	mer cleavage demethylation rate in compartment type, 1/day

The transformation rates may be input directly, or calculated based on other parameters. If both algorithms and input values are available, then the user will be able to choose which method to use.

A.2.1 ABIOTIC MERCURY TRANSFORMATION PARAMETERS

The information in Tables A-2 through A-13 is taken primarily from the 1997 Mercury Report to Congress (U.S. EPA 1997a) and model documentation for EPRI's R-MCM Mercury Cycling Model (Hudson et al. 1994).

Table A-2
Issues Related to Reduction of Hg(2) to Hg(0) in Soil, Surface Water, and Sediment

Soil	Surface Water	Sediment
Decreases in decreasing sunlight	Decreases with decreasing sunlight and temperatures	Sparse literature on subject
Abiotic reduction (transfer of electrons from humic acid to Hg(2)) is dependent on pH.	Has been observed to increase with decreasing dissolved organic carbon (DOC) conditions (Amyot et al. 1997), and vice versa, due to reduced light penetration and increased complexation of Hg(2)	
Strong stability complex between Hg(2) and humic acid.		

Table A-3
Reduction (k_r) in Surface Water: Inputs

Input Values (1/day)	Comment	Reference(s)
5E-1to 3.5	Experimental value using simulated sunlight, after normalizing to sunlight in Stockholm, Sweden	U.S. EPA (1997a), Xiao et al. (1995)
5E-3 to 1E-1	Based on mass balances in Wisconsin seepage lakes	U.S. EPA (1997a), Mason et al. (1994)
2E-2 to 4E-2	Epilimnion	Mason et al. (1995)
1E-2	9 m depth	Mason et al. (1995)
<5E-3	17 m depth	Mason et al. (1995)
1.4E-1	high Arctic lake during 24 hour sunlight period	Amyot et al. (1997)
2E-1 to 4E-1	high Arctic lake, low DOC conditions	Amyot et al. (1997)
2E-2 to 1.4E-1	high Arctic lake, high DOC conditions	Amyot et al. (1997)
1E-1	July-August, upper 3 m	Vandal et al. (1995)
5E-2	July August, upper 6 m	Vandal et al. (1995)

Table A-4
Reduction (k_r) in Sediment: Inputs

Input Values (1/day)	Comment	Reference(s)
1E-6	Inferred value calculated based on presence of Hg(0) in sediment porewater	U.S. EPA (1997a), Vandal et al. (1995)
0.216	Derived from humic acid from farm pool sediment. pH did not appear to affect the rate of reaction, but does seem to influence the amount of mercury reduced.	Alberts et al. (1974)

Table A-5
Reduction (k_r) in Soil: Inputs

Equations Used to Calculate Input Values	Comment	Reference(s)
$k_{norm}\ \theta\ z_{surf} / z_S$' where k_{norm} = reduction rate normalized by soil water content in the surficial 5 mm of soil, L[soil]/L[water]-day; values range from 1E-4 for forest site to 1.3E-3 for field site θ = soil water content, L[water]/L[soil] z_{surf} = depth of soil surface layer to which reduction rate is normalized, 5E-3 m z_S = soil layer depth, m	Formula is derived from evasion flux measurements	U.S. EPA (1997a), Carpi and Lindberg (1997)

Table A-6
Issues Related to Methylation in Soil, Surface Water, and Sediment

Soil	Surface Water	Sediment
Anaerobic conditions favor higher methylation rates[a]	Anaerobic conditions favor higher methylation rates[a]	Anaerobic conditions favor higher methylation rates[a]
Biotic methylation may occur due to bacteria; abiotic methylation by transmethylation from other organometals or by humic substances[b]	Photodegradation at surface can lower the gross methylation rate[c]	Highest rates may occur at the sediment surface (sulfate-reducing bacteria may be important mediators of the reaction), Gilmour and Henry (1991)
Increases with increasing organic carbon content and BHT[f]	Positively correlated with DOC[d]	Positively correlated with TOC (total organic carbon)[d]
Generally occurs for Hg(2) dissolved in soil porewater	Generally occurs for Hg(2) dissolved in water column[d]	Generally occurs for Hg(2) dissolved in sediment porewater[d]
Abiotic methylation is proportional to temperature and Hg(2) concentration. Also, it is inversely proportional to pH (at pH > 5)[g]	Positively correlated with temperature[d]	Positively correlated with temperature[d]
	Potentially positively correlated with sulfate concentration in water column[e]	Potentially positively correlated with sulfate concentration in sediment porewater[e]

a This is generally due to increased bacterial reactions in anaerobic conditions
b: U.S. EPA (1997a), Gilmour and Henry (1991)
c: Initial reference is Bob Ambrose's discussion of methylation in water column in U.S. EPA (1997a)
d: Hudson et al. (1994)
e: Watras et al. (1995)
f: Nagase et al. (1984); BHT = 2,6, di-tert-butyl-methyl phenol
g: Bodek et al. (1988)

Table A-7
Methylation (k_m) in Surface Water: Inputs

Input Values (1/day)	Comment	Reference(s)
1E-4 to 3E-3	reported as maximum potential methylation rate	Gilmour and Henry (1991)
6E-4 to 6E-3	Depth of 3 - 9m	U.S. EPA (1997a), based on Henry et al. (1995a, 1995b) and Jacobs et al. (1995)
5E-4 to 1E-3	Oxic portion of four forest lakes in Finland	Matilainen (1995)
1E-2 to 3E-2	At seasonally-anoxic depth of 15 m	U.S. EPA (1997a), based on Henry et al. (1995a, 1995b) and Jacobs et al., (1995)
4E-3 to 1E-2	Anaerobic layers of hypolimnion	Matilainen (1995)
1E-2 to 4E-2	0.5 - 1.0 m layer of bacterioplankton near the top of the anoxic hypolimnion	Watras et al. (1995)
Equations Used to Calculate Input Values		
$K_{MW}\ Q_{10m}^{(T-Tb)\ 0.1}\ C_{DOC} f_m f_{dissolved}^{II}\ C_s/(C_s+K_s),$ where K_{MW} = methylation rate in the water column, based on DOC (L/mg DOC/day) Q_{10m} = term to adjust methylation rate for temperature (implied suggested value in R-MCM documentation is 2, so that methylation rate doubles for every 10 degree increase in temperature above the base temperature) T = water column temperature, Celsius Tb = base temperature at which methylation rate constant K_{MW} applies, Celsius C_{DOC} = DOC concentration in water column, mg DOC/L f_m = fraction of the dissolved HgII in the water column available for methylation $f^{II}_{dissolved}$ = fraction of the Hg(2) in the water column that is dissolved C_s = concentration of sulfate in the water column, µeq/L K_s = half-saturation constant for the effect of sulfate on methylation, µeq/L	Will need to see what ranges are for K_{MW} and K_s	Hudson et al. (1994)

Table A-8
Methylation (k_m) in Sediment: Inputs

Input Values (1/day)	Comment	Reference(s)
1E-5 to 1E-3	Reported as maximum potential methylation rate	Gilmour and Henry (1991)
8E-4 to 2.5E-2	Above intact sediment cores	Stordal and Gill (1995)
8E-5 to 2E-5	Upper 4 cm of Little Rock Lake sediments	Calculated in U.S. EPA (1997a) from methylation rates in units of ug/m^2/day (Gilmour and Riedel 1995) and assumed dry density of 1.2 g/cm^3
Equations Used to Calculate Input Values		
$K_{MS}\ Q_{10m}^{(T-Tb)\,0.1}\ T_s f_m f_{dissolved}^{II}\ ((p_i - p_b)*0.5)\ C_{ps}/(C_{ps}+K_s),$ where K_{MS} = methylation rate in the sediment, based on TOC (m^2/g TOC/day) Q_{10m} = term to adjust methylation rate for temperature (implied suggested value in R-MCM documentation is 2, so that methylation rate doubles for every 10 degree increase in temperature above the base temperature) T = sediment temperature, Celsius Tb = base temperature at which methylation rate constant K_{MS} applies, Celsius T_s = TOC concentration in water column, g [organisms] C/m^2 f_m = fraction of the dissolved HgII in the sediment porewater available for methylation $f^{II}_{dissolved}$ = fraction of the Hg(2) in the sediment that is dissolved p_i = porosity of the sediment at the sediment/water interface, dimensionless p_b = porosity of the bottom of the sediment, dimensionless C_{ps} = concentration of sulfate in the sediment porewater, µeq/L K_s = half-saturation constant for the effect of sulfate on methylation, µeq/L	Will need to see what ranges are for K_{MS} and K_s. Also make sure porosity dependence is correct (seems odd).	Hudson et al. (1994), p.5-22

Table A-9
Methylation (k_m) in Soil: Inputs

Input Values (1/day)	Comment	Reference(s)
2E-4	average maximum potential methylation rate constant under aerobic conditions for 120-day experiment	Porvari and Verta (1995)
1E-3	average average maximum potential methylation rate constant under anaerobic conditions for 120-day experiment	Porvari and Verta (1995)
7E-5 to 9.7E-4	Range for median aerobic reaction rate (from peat, humus layer, and soil samples, respectively)	Verta et al (1994)
9.2 E-3	Anaerobic median rate of four inundated soil samples (range = 4.2E-3 to 1.2E-2/day)	Verta et al. (1994)

Table A-10
Issues Related to Demethylation in Soil, Surface Water, and Sediment

Soil	Surface Water	Sediment
May increase with increasing anaerobic conditions	Negatively correlated with light	May depend on bacteria processes
		Has been reported as maximal at the sediment/water interface (Gilmour et al. 1992)

Table A-11
Demethylation (k_m) in Surface Water: Inputs

Input Values (1/day)	Comment	Reference(s)
1E-3 to 2.5E-2	Maximum potential demethylation rate constants	Gilmour and Henry (1991)
Equations Used to Calculate Input Values		
$(K_{ds} / K_L) (1 - \exp(-K_L z_W)) / z_W$, where K_{ds} = demethylation rate constant at the lake surface, 1/day K_L = light extinction coefficient for use in demethylation calculations, 1/m z_W = mean depth of water column, m		Hudson et al. (1994)

Table A-12
Demethylation (k_{dm}) in Sediment: Inputs

Input Values (1/day)	Comment	Reference(s)
2E-4 to 1E-1	reported maximum potential demethylation rate constants	Gilmour and Henry (1991)
Equations Used to Calculate Input Values		
$K_{dms}\ T_s f^{MHg}_{dissolved}\ ((p_i + p_b) * 0.5)$, where K_{dms} = demethylation rate in the sediment, based on TOC (m^2/g TOC/day) T_s = TOC concentration in sediment, g [organisms] C/m^2 $f^{MHg}_{dissolved}$ = fraction of the methylmercury in the sediment that is dissolved p_i = porosity of the sediment at the sediment/water interface, dimensionless p_b = porosity of the bottom of the sediment, dimensionless	Will need to see what ranges are for K_{MS} and K_s. Also make sure porosity dependence is correct (seems odd).	Hudson et al. (1994)

Table A-13
Demethylation (k_{dm}) in Soil: Inputs

Input Values (1/day)	Comment	Reference(s)
3E-2	Average of maximum potential demethylation rate constants in aerobic conditions	Porvari and Verta (1995)
6E-2	Average of maximum potential demethylation rate constants in anaerobic conditions	Porvari and Verta (1995)
3.6E-2, 7.6E-2, 1.1E-1	Median aerobic rates for 15 inundated soil samples, 15 humus layer samples, and five peat samples, respectively.	Verta et al. (1994)
8.9E-2	Median anaerobic rate for 15 inundated soil samples.	Verta et al. (1994)

A.2.2 BIOTIC MERCURY TRANSFORMATION PARAMETERS

A.2.2.1 Plants

Fortmann et al. (1978) observed that some plants can change the mercury species accumulated from the environment. However, few studies are available from which to determine transformation rates.

$$Hg(0) \rightarrow Hg(2)$$

This transfer only occurs in leaves; elemental mercury is probably not taken up by the root. This rate is apparently very rapid and may be assumed to be instantaneous (U.S. EPA 1997a). No instances have been found where elemental mercury was measured in plants (*e.g.*, Cappon 1987). Thus, elemental mercury in air or on the surface of the leaf can be directly transferred to divalent mercury in the leaf.

$$Hg(2) \rightarrow \text{methylmercury}$$

It may be assumed that Hg(2) is not transformed. Although the in vivo transformation of inorganic mercury to methylmercury was observed in *Pisum sativum* (peas) in one study (Gay 1975), the chemical was ephemeral and quickly (several hours) decayed to low parts per billion levels. Methylmercury residues were not detected in mature crops following the addition of mercuric chloride to soil (Bache et al. 1973). Indeed, most mercury in plants is usually in inorganic form (Lindberg 1998).

$$\text{methylmercury} \rightarrow Hg(2)$$

This transfer occurs in leaves and stems, and not in roots (since transformations interfere with the equilibrium assumption in roots). It may be assumed that methylmercury is transformed to Hg(2) according to first-order kinetics, where the first-order rate constant is **0.03 per day**, based on the following calculation.

Only one study is available in which methylmercury was added to soil, and forms of mercury (methyl and total) were measured after a defined period of exposure (Bache et al. 1973). In the few other studies of speciation of mercury within plants, either it is not known which species were present in soil (*e.g.*, Heller and Weber 1998), or multiple Hg species were present in soil and it is not known which were initially taken up by the plant (Cappon 1987).

Using data from Bache et al. (1973) Table A-14, it may be assumed that the methylmercury is readily taken up through the roots or foliage, that equilibrium between soil and plant is achieved quickly, that methylmercury is not appreciably transformed in soil during a crop season, that all methylmercury is only transformed to ionic mercury, and that crops were harvested after 40 days. Under these assumptions, 1st order rate constants for the transformation of methylmercury to Hg(2) vary by almost two orders of magnitude in a single study. No mechanistic explanation is available for this high degree of variability.

Table A-14
Concentrations of Methylmercury in Foliage and Stems of Crops from Bache et al. (1973) and Associated First-order Rate Constants, Using Assumptions in Text

Plant Species	Soil	Application to Soil (mg/kg)	Total Mercury in Foliage and Stem	Methylmercury in Foliage and Stem	1st Order Rate Constant (d^{-1})
Bush bean (*Phaseolus vulgaris*)	gravelly loam	1	52	46	0.003
Bush bean (*Phaseolus vulgaris*)	gravelly loam	10	90	28	0.03
Carrot (*Daucus carota*)	gravelly loam	10	214	1	0.1
Potato (*solanum tuberosum*)	silt loam	1	86	27	0.03
Potato (*solanum tuberosum*)	silt loam	10	58	17	0.03
Tomato (*Lycopersicon esculantum*)	gravelly loam	10	341	3	0.1

A.2.2.2 Soil Detritivores

No information is available for transformations of mercury in soil detritivores. In addition, transformation algorithms cannot be implemented if the mercury in these organisms is in equilibrium with mercury in root-zone soil.

A.2.2.3 Terrestrial and Semi-aquatic Wildlife

Little quantitative information is available on the transformation of mercury in mammals and birds. Where information is available, calculations of rate constants assume first order transformations and are calculated on the basis of the total chemical taken up by the organism but not necessarily assimilated. (The exception is the inhalation pathway, where rate constants are derived based on the absorbed fraction.)

$$Hg(0) \rightarrow Hg(2)$$

No information is available from which to derive transformation rate constants for the oxidation of elemental mercury to the mercuric ion. Based on the following information, it may be assumed that the rate is rapid, and 1 day^{-1} is a rough estimate of the first-order rate constant. Elemental mercury is readily oxidized to the inorganic divalent species in most tissues following the hydrogen peroxidase-catalase pathway. This oxidation primarily occurs in the red blood cells

and hydrogen peroxide is probably the rate-determining step (ATSDR 1997, U.S. EPA 1997b). Once it is oxidized to the mercuric ion, it is indistinguishable from Hg(2) from inorganic sources (ATSDR 1997, U.S. EPA 1997b).

$$Hg(2) \rightarrow Hg(0)$$

Mercuric salts primarily remain in their divalent form. However, a small fraction of the inorganic divalent cation can be reduced to elemental mercury and exhaled as a vapor (ATSDR 1997). However, no information is available from which to derive this transformation rate constant. For this reason, the transformation is assumed not to occur.

$$\text{organic mercury} \rightarrow Hg(2)$$

Forms of organic mercury are the most studied species of mercury. The short-chain alkyl mercury compounds (*e.g.* methylmercury) are relatively stable and are more slowly metabolized to the inorganic form (U.S. EPA 1997b) The long-chain compounds may be more readily metabolized to the mercuric ion (U.S. EPA 1997b). Takeda and Ukita (1970) dosed Donryu rats with 20 µg Hg/kg ethyl-mercuric chloride via intravenous injection. After 8 days, 58.1 percent of the mercury excreted in the urine was inorganic mercury and 35 percent of the mercury excreted in feces was inorganic (Table A-15). If it is assumed that 1) the excreted chemicals reflect the transformation rate in the animal (transformation occurred immediately prior to excretion) and 2) the first-order rate reflects a weighted average of the amount of dose excreted in urine (10.52 percent) and that excreted in feces (6.01 percent), then the transformation rate may be estimated to be 0.09 day^{-1}.

Table A-15
Transformation Rate (day^{-1}) of Organic Mercury to the Inorganic Divalent Form (Takeda and Ukita 1970)

Class	Elimination Type	Dose Route	% Organic after 8 days	% Inorganic after 8 days	Transform Rate Constant
Mammalia	urine	injection	41.9	58.1	0.1084
	feces	injection	65.0	35.0	0.0539
	assumed transformation for whole animal				0.09

$$Hg(2) \rightarrow \text{organic mercury}$$

No information is available on this transformation. Therefore it is assumed to be zero.

Miscellaneous Transformations

Miscellaneous transformations in wildlife are presented for the sake of completeness but are not included in TRIM.FaTE at this time. Mercurous salts are transformed to the divalent ion and elemental mercury when in contact with sulfhydryl groups (ATSDR 1997).

A.2.2.4 Aquatic Species

Transformations of mercury in algae, macrophytes, and benthic organisms are assumed not to occur.

$$Hg(2) \rightarrow \text{organic mercury}$$

Very little is known about the rate at which transformation of mercury species occurs in aquatic organisms. A large body of field data suggests that most (> 90 percent) of mercury in fish is in the form of methylmercury and other organic species. For this reason, it is assumed that the first-order rate constant for the conversion is 1 day^{-1}.

$$Hg(0) \rightarrow Hg(2)$$

This transformation is assumed to occur instantaneously in fish.

$$Hg(0) \rightarrow \text{organic mercury}$$

This transformation is assumed not to occur directly in fish.

$$Hg(2) \rightarrow \text{organic mercury}$$

This transformation is assumed not to occur in fish.

$$\text{organic mercury} \rightarrow Hg(2)$$

This transformation is assumed not to occur in fish.

$$\text{organic mercury} \rightarrow Hg(0)$$

This transformation is assumed not to occur in fish.

A.3 INPUT PARAMETERS SPECIFIC TO MERCURY EXCRETION BY BIOTA

First-order rate constants for the elimination of mercury from wildlife are summarized in Table A-16. Supporting information is presented below.

Table A-16
Mean First-order Rate Constants (day^{-1}) for Elimination of Mercury from Birds and Mammals

	Chemical Species	Urine and Feces (E_u)	Lactation (E_l)	Eggs (E_e)	Fur, Feathers, or Hair (E_f)
mammals	Hg(2)	0.48[a]	0.00001	NA	0.00001
	Hg(0)	0.0502[b]	0[b]	NA	0[b]
	organic Hg	0.26[a]	0.00001[c]	NA	0.00014[d]
birds	Hg(2)	0.48[e]	NA	0[f]	0.00011[g]
	Hg(0)	0[b]	NA	0[b]	0[b]
	organic Hg	0.0282[a]	NA	0.0244	0.0559

[a] Averages of elimination rate constants for oral and dietary doses
[b] Rate constant based on inhalation study
[c] Assume same as lactation rate constant for Hg(2)
[d] Averages of elimination rate constants for oral dose and injection
[e] Assume same as elimination rate constant to mammalian urine and feces
[f] No information available
[g] Assume same as elimination rate constant to mammal fur

A.3.1 ELEMENTAL MERCURY

Elemental mercury vapor is rapidly absorbed in the lungs (75 to 85 percent in humans), and to a much lesser extent (three percent), it can be absorbed dermally (ATSDR 1997, U.S. EPA 1997b). Five human subjects inhaled from 107 to 202 $\mu g/m^3$ Hg and retained an average of 74 percent of the dose (Teisinger and Fiserova-Bergerova 1965). The inhaled vapor readily distributes throughout the body and can cross the blood-brain and placental barriers.

Rats exposed for 5 hours to 1.4 mg/m^3 radio-labeled mercury vapor retained an average body burden of 0.256 mg/kg BW (37 µg Hg/rat) and had excreted (urine and feces) 8.5 percent of the initial body burden in 1 day, 24.8 percent in 5 days, and 42.9 percent in 15 days (Hayes and Rothstein 1962). Cherian et al. (1978) exposed 5 human volunteers to approximately 1 µCi of radio-labeled Hg vapor for approximately 19 minutes. Mean cumulative excretion over the first 7 days after exposure was 2.4 percent of the retained dose in urine and 9.2 percent in feces for a total excretion of 11.6 percent of the retained dose (Cherian et al. 1978).

Rates of excretion of elemental mercury by mammals (rats and humans) are summarized in Table A-17. The mean value is presented in Table A-16. No information on excretion by avian species is available.

Table A-17
Excretion of Elemental Mercury (Hg^0) in Mammals.

Test Species	Dose	Dose Route[1]	Elimination Route	Percent of Dose	Days	Rate Constant (Day^{-1})	Source
Rat	0.256 mg/kg	inh	urine + feces	8.5	1	0.08883	Hayes & Rothstein 1962
Rat	0.256 mg/kg	inh	urine + feces	24.8	5	0.05700	Hayes & Rothstein 1962
Rat	0.256 mg/kg	inh	urine + feces	42.9	15	0.03736	Hayes & Rothstein 1962
Human	1 µCi	inh	urine + feces	11.6	7	0.01761	Cherian et al. 1978
				$\bar{x} \pm$ SE		**0.05020 ± 0.01518**	

[1] inh = inhalation

A.3.2 Divalent Mercury

Divalent mercury can be absorbed through oral, dermal, and inhalation routes; however, absorption is inefficient for all pathways. In mice, only 20 percent of the administered dose is absorbed from the GI tract, 2-3 percent of the dose was absorbed dermally in exposed guinea pigs, and limited information on inhalation exposure indicates that 40 percent of the dose was absorbed in the lungs of dogs (U.S. EPA 1997b). Additionally, the absorption of mercuric salts varies with the solubility of the specific salt. For example, the less soluble sulfide salt is more poorly absorbed as mercuric sulfide than the more soluble chloride salt as mercuric chloride (U.S. EPA 1997b). Divalent mercury distributes widely throughout the body, however, it cannot cross the blood-brain or placental barriers.

The metabolism and distribution of mercuric chloride ($HgCl_2$) has been described in dairy cows and rats. Potter et al. (1972) orally administered 344 µCi of radio-labeled mercuric chloride by gelatin capsule using balling gum to 2 Holstein cows. After 6 days, 94.87 percent of the dose was excreted in feces, 0.044 percent in urine, and 0.0097 percent in milk, for a total excretion of 94.924 percent of the dose. The biological half-life was calculated as 28.5 hours. Rats dosed by intravenous injection with 1 mg/kg mercuric chloride excreted 15.2 percent of the dose in feces and 16.3 percent in urine over 4 days for a total excretion (fecal and urinary) of 31.5 percent of the administered dose (Gregus and Klaassen 1986).

The metabolism and distribution of mercuric nitrate [$Hg(NO_3)_2$] has also been described in dairy cows and rats. Four Holstein dairy cows were given an oral dose of 1.7 mCi radio-labeled $Hg(NO_3)_2$ in a gelatin capsule via balling gum. Urine, feces, and milk were collected for 10 days and analyzed. Results indicated that 74.91 percent of the dose was excreted in feces, 0.08 percent in urine, and 0.01 percent in milk with a total excretion of 75 percent of the dose (Mullen et al. 1975). Mullen et al. (1975) also reported a biological half-life for the transfer of

orally ingested mercury to milk of 5 days. Transfer of mercury to feces was slightly more complicated with an initial half-life of 15 hr, then a decrease in elimination time which resulted in a 3 day half-life (Mullen et al. 1975). Rothstein and Hayes (1960) dosed seven Wistar rats with 50 µg (0.2 mg/kg BW) radio-labeled mercury as $Hg(NO_3)_2$ via intravenous injection. After 52 days the cumulative percent excretion was 25 percent of the administered dose in urine and 37 percent in feces for a total excretion of 62 percent of the dose (Rothstein and Hayes 1960). In another study, 6 Holtzman rats were dosed by subcutaneous injection with 20 µCi of radio-labeled $Hg(NO_3)_2$ and 0.018 percent of the dose was recovered in the hair 20 days after administration (Mansour et al. 1973). The maternal clearance half-time of 16.2 days was also reported.

Fitzhugh et al. (1950) exposed rats (n=20/dose group) to mercuric acetate in the diet at doses of 0.5, 2.5, 10, 40, and 160 ppm. The average intake of Hg in a 24 hour period was 7.5, 37.5, 150, 600, and 2,400 µg and the 24 hour excretion was 52, 40, 43, 47, and 43 percent of these doses, respectively, in feces and 4.8, 1.0, 0.5, 0.37, and 1.7 percent, respectively, in urine (Fitzhugh et al. 1950).

Divalent mercury is very poorly absorbed from the GI tract, therefore, rates obtained from oral or dietary exposure may be misleading. Hayes and Rothstein (1962) reported an initial half-life for fecal excretion of inorganic mercury of 0.6 days in Holstein cows. Later, the half-life increased to 3 days. This indicates that a large proportion of the dose is initially excreted via the feces due to lack of absorption. Thus, it may be necessary to correct the oral and dietary fecal elimination rates for inorganic mercury using assimilation factors.

Rates of excretion of divalent mercury by mammals (rats and cows) are summarized in Table A-18. The mean values for excretion to urin and feces, lactation, and excretion to hair are presented in Table A-16. No information on excretion by avian species is available.

A.3.3 ORGANIC MERCURY

Organic mercury was by far the most studied species of mercury. It is rapidly and extensively absorbed through the GI tract (95 percent of the dose in humans) and is distributed throughout the body via carrier-mediated transport (U.S. EPA 1997b). Like elemental mercury, organic mercury can cross the blood-brain and placental barriers.

Radio-labeled methylmercuric chloride was intravenously injected into 6 Holtzman rats at a dose of 10 µCi, and after 20 days 0.21 percent of the administered dose was transferred to hair. The clearance half-life was reported to be 8.4 days (Mansour et al. 1973). Gregus and Klaassen (1986) also administered radio-labeled methylmercuric chloride via intravenous injection to

Table A-18
Excretion of Divalent Mercury in Mammals

Test Species[a]	Form	Dose	Dose[b] Route	Elimination Route	Percent of Dose	Days	Rate (Day^{-1})	Dose Vehicle	Source
Cow-Holstein	$HgCl_2$	344 µCi	oral	urine + feces	94.91	6	0.49632	gel cap	Potter et al. 1972
Cow-Holstein	$Hg(NO_3)_2$	1.7 mCi	oral	urine + feces	74.99	10	0.13859	gel cap	Mullen et al. 1975
					$\bar{x} \pm$ SE		**0.31745 ± 0.17886**		
Rat-SD	$HgCl_2$	1 mg/kg	iv	urine + feces	31.5	4	0.09458	saline sol	Gregus & Klaassen 1986
Rat-Wistar	$Hg(NO_3)_2$	50 µg	iv	urine + feces	62	52	0.01861	sodium chloride	Rothstein & Hayes 1960
					$\bar{x} \pm$ SE		**0.05660 ± 0.03798**		
Rat	mercuric acetate	7.5 µg	diet	urine + feces	56.8	1	0.83933	food	Fitzhugh et al. 1950
Rat	mercuric acetate	37.5 µg	diet	urine + feces	41.0	1	0.52763	food	Fitzhugh et al. 1950
Rat	mercuric acetate	150 µg	diet	urine + feces	43.5	1	0.57093	food	Fitzhugh et al. 1950
Rat	mercuric acetate	600 µg	diet	urine + feces	47.37	1	0.64188	food	Fitzhugh et al. 1950
Rat	mercuric acetate	2400 µg	diet	urine + feces	44.7	1	0.59240	food	Fitzhugh et al. 1950
					$\bar{x} \pm$ SE		**0.63443 ± 0.05443**		
Cow-Holstein	$HgCl_2$	344 µCi	oral	milk	0.0097	6	0.00002	gel cap	Potter et al. 1972
Cow-Holstein	$Hg(NO_3)_2$	1.7 mCi	oral	milk	0.01	10	0.00001	gel cap	Mullen et al. 1975
					$\bar{x} \pm$ SE		**0.00001 ± 0.000003**		
Rat-Holtzman	$Hg(NO_3)_2$	20 µg	sc inj	hair	0.018	20	0.00001	injection	Mansour et al. 1973

[a] Rat-SD = Sprague Dawley rat
[b] iv = Intravenous injection and sc inj = subcutaneous injection.

Sprague-Dawley rats at a dose of 1 mg/kg. Within 4 days, 5.6 percent of the dose was excreted in feces and 0.5 percent in urine for a total excretion of 6.1 percent of the administered dose. Additionally, 2 hr biliary excretion was 0.7, 0.9, 0.7, and 0.5 percent of doses 0.1, 0.3, 1.0, and 3.0 mg/kg, respectively (Gregus and Klaassen 1986). Syrian Golden hamsters (n=9) were given an oral dose of 0.32 mg Hg/kg BW as radio-labeled methylmercury chloride, and the elimination rate was found to follow a first-order rate equation with a half-life of 6.9 days (Nordenhäll et al. 1995). Nordenhäll et al. (1995) estimated that approximately 5 percent of the dose administered to the dams was transferred to pups via milk over 21 days. Four days post-administration of methylmercury chloride, 20 percent of the mercury in milk was inorganic (Nordenhäll et al. 1995). Sell and Davison (1975) dosed via intraruminal injection, 1 Nubian goat and 1 Guernsey cow with 100 and 500 µCi radio-labeled methylmercury chloride, respectively. After 13 days, 0.28, 31.18, and 1.45 percent of the dose administered to the goat were excreted in milk, feces, and urine, respectively. Conversely, none of the dose was excreted in cow milk, 25.32 percent was excreted in cow feces, and 1.28 percent was excreted in cow urine after 7 days.

Takeda and Ukita (1970) exposed Donryu rats to 20 µg Hg/kg BW as radio-labeled ethyl-mercuric chloride dissolved in olive oil by subcutaneous injection. Cumulative excretion during 8 days post-exposure was 10.52 percent of dose in urine and 6.01 percent of dose in feces. In urine, 41.9 percent and 58.1 percent of the total mercury was organic and inorganic, respectively, on day 8. In contrast, 65 percent of fecal mercury was organic and 35 percent was inorganic on day 8 (Takeda and Ukita 1970). Fang and Fallin (1973) orally dosed 14 rats with 3 µmol radio-labeled ethyl-mercuric chloride in corn oil. Mercury content was measured in 1-2 rats on days 0.25, 1, 2, 3, 4, 5, 7, 10, and 14 after dosing. Fourteen days after dosing, 32.5 nmole/g hair had accumulated in the fur. Wistar rats have an estimated 3 g of fur (Talmage 1999), therefore, approximately 3.25 percent of the original dose was excreted in hair.

Fitzhugh et al. (1950) exposed rats (n=20/dose group) to phenyl mercuric acetate in the diet at doses of 0.5, 2.5, 10, 40, and 160 ppm. The average intake of Hg in a 24 hour period was 7.5, 37.5, 150, 600, and 2,400 µg and the 24 hour excretion was 44, 35, 27, 35, and 30 percent of these doses, respectively, in feces and 9.2, 4.5, 6.2, 4.3, and 2.4 percent, respectively, in urine (Fitzhugh et al. 1950).

Humans have also been used as subjects for determining the metabolism of methylmercury. Three subjects were given an oral dose of 2.6 µCi radio-labeled methylmercuric nitrate (Aberg et al. 1969). Mean cumulative mercury excretion 10 days post-exposure were 13.6 percent (13.6, 13, and 14.2 percent) of dose in feces and 0.24 percent (0.18, 0.26, and 0.27 percent) in urine, and after 49 days, 34.1 percent (33.4 and 34.7 percent) of the initial dose was excreted via feces and 3.31 percent (3.29 and 3.33 percent) via urine (Aberg et al. 1969). Aberg et al. (1969) also reported the biological half-life of methylmercuric chloride to be 70.4, 74.2, and 73.7days ($\bar{x}$ = 72.8 days) for the three subjects and measured approximately 0.12 percent of the initial dose in hair approximately 45 days (range 40-50 days) after exposure.

Two papers contained data suitable for use in determining excretion rates for avian species. In the first study, Lewis and Furness (1991) orally dosed black-headed gulls with 200, 100, or 20 µl methylmercuric chloride using gelatin capsules. The cumulative excretion of mercury in the 200 µL group was 26.4 percent of the dose in feces and 51.2 percent in feathers

for a total of 77.5 percent in all excreta over 13 days. At the 100 µL dose, a total of 80.3 percent of the dose was excreted (37.8 and 44.2 percent in feces and feathers, respectively) in 13 days. Finally, only 56.3 percent of the low dose was measured in all excreta with 11 percent of the dose in feces and 52.6 percent in feathers after 13 days (Lewis and Furness 1991).

In the second study, 4 white-leghorn chickens and 4 Japanese quail were dosed with 20 ppm Hg as methylmercuric chloride in the diet for 21 days (Sell 1977). The first 7 days of this dosing period, chickens and quail were also given an oral dose of 2 µCi of radio-labeled methylmercuric chloride (Sell 1977). The rate calculations reported in Table A-17 assume that the author accounted for the total intake of radio-labeled mercury from both sources when reporting percent of dose excreted in feces and eggs. Chickens excreted 64 percent of the dose in feces and 21.88 percent of the dose in eggs produced during the 21 days post-exposure, while quail excreted 41 and 54.08 percent of the dose in feces and eggs, respective, during the same 21 day post-exposure period (Sell 1977).

Rates of excretion of organic mercury by mammals (humans, goats, cows, and rats) are summarized in Table A-19. Rates of excretion by birds are summarized in Table A-20. The mean values for excretion to urine and feces, fur, feathers, and eggs are presented in Table A-16. No information on excretion by avian species is available.

Table A-19
Excretion of Organic Mercury in Mammals

Test Species[1]	Form	Dose	Dose[2] Route	Elimination Route	Percent of Dose	Days	Rate (Day^{-1})	Dose Vehicle	Source
Human	methylmercuric nitrate	2.6 µCi	oral	urine + feces	13.84	10	0.01490	aq sol	Aberg et al. 1969
Human	methylmercuric nitrate	2.6 µCi	oral	urine + feces	37.41	49	0.00956	aq sol	Aberg et al. 1969
Goat-Nubian	CH_3-HgCl	100 µCi	ir inj	urine + feces	0.67	1	0.00672	ethanol	Sell & Davison 1975
Goat-Nubian	CH_3-HgCl	100 µCi	ir inj	urine + feces	17.19	3	0.06287	ethanol	Sell & Davison 1975
Goat-Nubian	CH_3-HgCl	100 µCi	ir inj	urine + feces	22.62	5	0.05129	ethanol	Sell & Davison 1975
Goat-Nubian	CH_3-HgCl	100 µCi	ir inj	urine + feces	25.72	7	0.04248	ethanol	Sell & Davison 1975
Goat-Nubian	CH_3-HgCl	100 µCi	ir inj	urine + feces	31.63	13	0.02925	ethanol	Sell & Davison 1975
Cow-Guernsey	CH_3-HgCl	500 µCi	ir inj	urine + feces	4.80	1	0.04919	ethanol	Sell & Davison 1975
Cow-Guernsey	CH_3-HgCl	500 µCi	ir inj	urine + feces	18.86	3	0.06966	ethanol	Sell & Davison 1975
Cow-Guernsey	CH_3-HgCl	500 µCi	ir inj	urine + feces	23.05	5	0.05240	ethanol	Sell & Davison 1975
Cow-Guernsey	CH_3-HgCl	500 µCi	ir inj	urine + feces	26.60	7	0.04418	ethanol	Sell & Davison 1975
					$\bar{x} \pm$ SE		**0.03932 ± 0.00644**		
Rat-SD	CH_3-HgCl	1 mg/kg	iv	urine + feces	6.1	4	0.01573	saline sol	Gregus & Klaassen 1986
Rat-Donryu	ethyl-$HgCl_2$	20 µg/kg	sc inj	urine + feces	16.53	8	0.02259	olive oil	Takeda & Ukita 1970
					$\bar{x} \pm$ SE		**0.01916 ± 0.00343**		
Rat	phenyl mercuric acetate	7.5 µg	diet	urine + feces	53.2	1	0.75929	food	Fitzhugh et al. 1950
Rat	phenyl mercuric acetate	37.5 µg	diet	urine + feces	39.5	1	0.50253	food	Fitzhugh et al. 1950
Rat	phenyl mercuric acetate	150 µg	diet	urine + feces	33.2	1	0.40347	food	Fitzhugh et al. 1950
Rat	phenyl mercuric acetate	600 µg	diet	urine + feces	39.3	1	0.49923	food	Fitzhugh et al. 1950
Rat	phenyl mercuric acetate	2400 µg	diet	urine + feces	32.4	1	0.39156	food	Fitzhugh et al. 1950
					$\bar{x} \pm$ SE		**0.51121 ± 0.06621**		
Goat-Nubian	CH_3-HgCl	100 µCi	ir inj	milk	0.08	3	0.00027	ethanol	Sell & Davison 1975

Table A-19 (cont.)
Excretion of Organic Mercury in Mammals

Test Species[1]	Form	Dose	Dose[2] Route	Elimination Route	Percent of Dose	Days	Rate (Day^{-1})	Dose Vehicle	Source
Goat-Nubian	CH_3-HgCl	100 µCi	ir inj	milk	0.14	5	0.00028	ethanol	Sell & Davison 1975
Goat-Nubian	CH_3-HgCl	100 µCi	ir inj	milk	0.19	7	0.00027	ethanol	Sell & Davison 1975
Goat-Nubian	CH_3-HgCl	100 µCi	ir inj	milk	0.28	13	0.00022	ethanol	Sell & Davison 1975
					$\bar{x} \pm$ SE		**0.00026 ± 0.00001**		
Human	methylmercuric nitrate	2.6 µCi	oral	hair	0.12	45	0.00003	aq sol	Aberg et al. 1969
Rat-Wistar	ethyl-$HgCl_2$	3 µmole	oral	hair	0.05	0.25	0.00200	corn oil	Fang & Fallin 1973
Rat-Wistar	ethyl-$HgCl_2$	3 µmole	oral	hair	0.14	1	0.00140	corn oil	Fang & Fallin 1973
Rat-Wistar	ethyl-$HgCl_2$	3 µmole	oral	hair	0.18	2	0.00090	corn oil	Fang & Fallin 1973
Rat-Wistar	ethyl-$HgCl_2$	3 µmole	oral	hair	0.52	3	0.00174	corn oil	Fang & Fallin 1973
Rat-Wistar	ethyl-$HgCl_2$	3 µmole	oral	hair	0.59	4	0.00148	corn oil	Fang & Fallin 1973
Rat-Wistar	ethyl-$HgCl_2$	3 µmole	oral	hair	0.67	5	0.00134	corn oil	Fang & Fallin 1973
Rat-Wistar	ethyl-$HgCl_2$	3 µmole	oral	hair	1.08	7	0.00155	corn oil	Fang & Fallin 1973
Rat-Wistar	ethyl-$HgCl_2$	3 µmole	oral	hair	2.25	10	0.00228	corn oil	Fang & Fallin 1973
Rat-Wistar	ethyl-$HgCl_2$	3 µmole	oral	hair	5.50	14	0.00404	corn oil	Fang & Fallin 1973
					$\bar{x} \pm$ SE		**0.00168 ± 0.00033**		
Rat-Holtzman	CH_3-HgCl	10 µCi	iv	hair	0.21	20	0.00011		Mansour et al. 1973

[1] Rat-SD = Sprague Dawley rat
[2] ir = Intraruminal injection, iv = intravenous injection and sc inj = subcutaneous injection.

Table A-20
Excretion of Organic Mercury in Birds

Test Species[a]	Form	Dose	Dose Route	Elimination Route	Percent of Dose	Days	Rate (Day^{-1})	Dose Vehicle	Source
Gull-BH	methyl-HgCl	200 µL	oral	feces	26.4	13	0.02358	gel cap	Lewis & Furness 1991
Gull-BH	methyl-HgCl	100 µL	oral	feces	37.7	13	0.03640	gel cap	Lewis & Furness 1991
Gull-BH	methyl-HgCl	20 µL	oral	feces	11	13	0.00896	gel cap	Lewis & Furness 1991
					$\bar{x}$ ± SE		**0.02298 ± 0.00793**		
Chicken-WL	methyl-HgCl	20 ppm + 2 µCi	diet/orl	feces	64	21	0.04865	food	Sell 1977
Quail-Japanese	methyl-HgCl	20 ppm + 2 µCi	diet/orl	feces	32	21	0.01836	food	Sell 1977
					$\bar{x}$ ± SE		**0.03351 ± 0.01514**		
Gull-BH	methyl-HgCl	200 µL	oral	feathers	51.2	13	0.05519	gel cap	Lewis & Furness 1991
Gull-BH	methyl-HgCl	100 µL	oral	feathers	44.2	13	0.04488	gel cap	Lewis & Furness 1991
Gull-BH	methyl-HgCl	20 µL	oral	feathers	52.6	13	0.05743	gel cap	Lewis & Furness 1991
					$\bar{x}$ ± SE		**0.05593 ± 0.00075**		
Chicken-WL	methyl-HgCl	20 ppm + 2 µCi	diet/orl	eggs	21.88	21	0.01176	food	Sell 1977
Quail-Japanese	methyl-HgCl	20 ppm + 2 µCi	diet/orl	eggs	54.08	21	0.03706	food	Sell 1977
					$\bar{x}$ ± SE		**0.02441 ± 0.01265**		

[a] Gull-BH = Black-headed gull, Chicken-WL = White- leghorn chicken.

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